PALEO-HEAT FLOWS AND THE MAGNETIC AND CLIMATIC HISTORY OF MARS.

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Introduction: Paleo-heat flow estimates based on determinations of lithospheric strength indicate that Mars has been losing less heat than predicted by most of thermal history models (see [1] and references therein). The martian mantle could even been heating-up during a substantial portion of its evolutionary history. This conclusion is consistent with evidence suggesting a currently fluid core, limited secular contraction for Mars, and recent extensive volcanism [1].

Additionally, recent petrologic modeling [2-4] of magma production finds higher potential mantle temperature for magmas originating shergottite meteorites (which typically have ages ~0.5 Ga) than for magmas originating Gusev and Meridiani basaltic rocks (which are Noachian in age). Shergottite meteorites could have originated in a hot-plume environment, and therefore be not representative of the average mantle, but a heating-up mantle would be a solution to the problem of the "hot shergottites".

Here we discuss the timing and implications of such a heating-up for the magnetic and climatic evolution of Mars.

Urey ratio, heat flow, and lithospheric strength: Figure 1 shows estimates of Urey ratio (*Ur*), as a function of time, derived from paleo-heat flows obtained by [1] and the compositional model of [5]. The Urey ratio is the ratio between the total radioactive heat production and the total heat loss through the surface of a planetary body. The represented *Ur* values were calculated extrapolating heat flows obtained for a given region to the entire planet. It is obvious that those "local" paleo-heat flows are not necessarily representative of average values, but so-derived "equivalent" *Ur* values are certainly interesting and informative. We have selected upper limits on the surface heat flow for a given feature and time, which in turn gives lower limits for *Ur*, being therefore the less favorable cases for a heating-up of the martian interior; indeed, for $Ur > 1$ ($Ur < 1$) the interior is heating (cooling)-up.

Figure 1 shows that most of heat flows derived for Noachian terrains are consistent with $Ur < 1$. Also, heat flows for volcanic regions would be consistent with $Ur < 1$ if these regions were loaded in the Amazonian, although volcanic areas are more dissipative than planetary averages. However, crater counts suggest early ages for the emplacement of Elysium and Tharsis volcanoes [6], and therefore $Ur > 1$ values are favored by these features. Post-Noachian non-volcanic regions suggest *Ur* values higher than, or close to, 1. Thus, the conclusion of a heating-up interior for post-Noachian times seems solid.

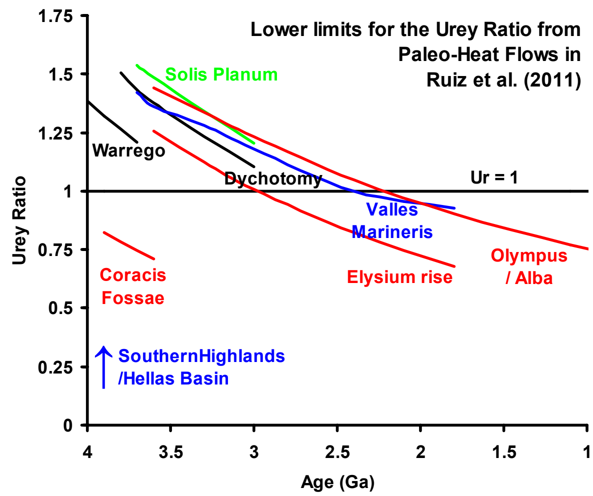

Fig. 1. Lower limits for *Ur* calculated from Paleo-heat flow values in [1]. Curves length indicate uncertainty related to feature age, not to temporal evolution.

If the heat flow is sufficiently low, the upper mantle is strong and contributes to the strength of the lithosphere, and hence to the effective elastic thickness of the lithosphere (T_e). Conversely, for a sufficiently high heat flow the upper mantle does not contribute to T_e, and the lithosphere is restricted to the crust. Figure 2 shows T_e values for several regions of Mars (including regions for which there are not heat flow calculations), with a general indication of the age loading. Most of T_e for Noachian times are very low or upper limits, suggesting a comparatively high flow in that time. Othewise, most of T_e for Hesperian/Amazonian or Amazonian times are high, implying an important contribution of the upper mantle to the strength of the lithosphere. Noachian/Hesperian or Hesperian loaded regions shows a wide dispersion of T_e values, generally higher than for Noachian, and very high values appears. The transition between low and high values of $T_{e,}$ and the onset of mantle contribution to the strength of the lithosphere occurred around the Noachian/Hesperian boundary, similarly to the inferred starting for *Ur* > 1 values.

Implications for magnetic and climatic history: The timing for relatively low heat flows and mantle contribution to the strength of the lithosphere is similar to the age of the transition from abundant hydrologic activity to more dry conditions and associated dropping of aquous erosion/degradation of landscape features [7]. Similarly, recent careful examination of the age of some magnetic anomalies suggests a cessation of the martian dynamo about 3.6-3.8 Ga [8-9]. The two later events could be related [9], because dynamo cessation would cause the end of the magnetic shielding of the atmosphere, contributing therefore to the severe erosion of the atmosphere of Mars.

We suggest here that all those processes could be linked: the rise of mantle temperature caused by an interior heating-up would have reduced the thermal gradient between mantle and core, stopping core convection and dynamo. This, in turn, would eliminate the magnetic shielding of the atmosphere and would affect climate and hydrologic evolution of Mars.

Low post-Noachian heat flow values could be explained by inefficient water recycling in a stagnant-lid planet [10]. Thus, it is possible that the evolution of water cycles in Mars had profound interrelations.

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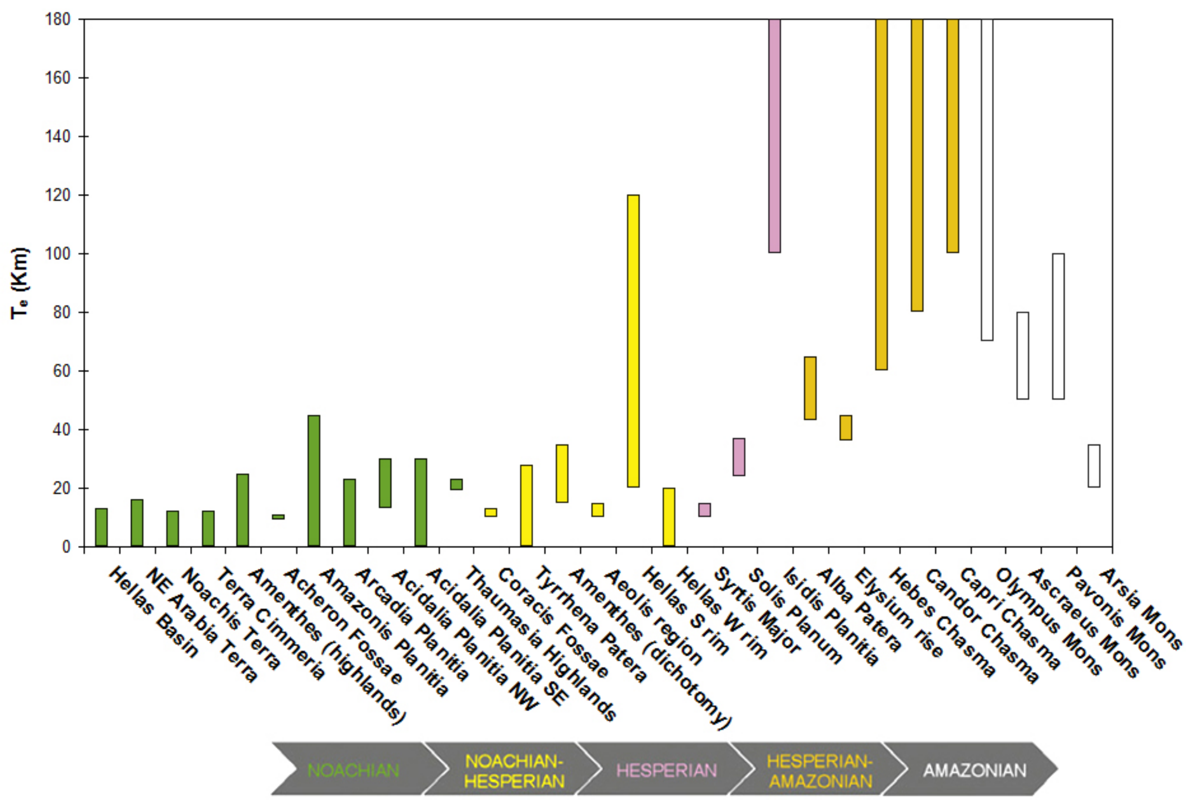

Fig. 2. Values of the martian elastic lithosphere thickness as a function of approximate age, compiled from several sources [e.g., 11-13]. For several features (e.g. Tharsis volcanoes) the indicated T_e is the range consistent with estimates by different authors.